AUTOTHERMAL REACTOR AND METHOD FOR
## PRODUCTION OF SYNTHESIS GAS

Field of the Invention

[0001]   The present invention relates to an autothermal reactor and method for producing a synthesis gas comprising hydrogen and carbon monoxide. More particularly, the present invention relates to such a reactor and method in which a reactant stream is produced by entraining a hydrocarbon containing stream in an oxygen containing stream that is expanded into a mixing chamber and the reactant stream is initially reacted in a partial oxidation stage and subsequently reacted in endothermic reforming stages.

Background of the Invention

[0002]   The need exists for small, safe on-site reactors to produce synthesis gas, that is a gas containing carbon monoxide and hydrogen, for use in subsequent chemical reactions or as a fuel. Synthesis gas is produced by known partial oxidation and steam methane reforming reactions or a combination of the two known as autothermal reforming.

[0003]   In a partial oxidation reaction, a hydrocarbon containing stream, for instance, natural gas, oxygen and, optionally, steam are introduced into a partial oxidation reactor with the use of a specially designed burner. The oxygen is consumed at the reactor entrance. The residence time in the reactor is about 3 seconds. The overall reaction that takes place is:
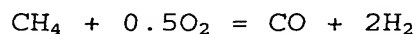
$$CH_4 + 0.5O_2 = CO + 2H_2$$

The following side reactions also occur.

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$H_2 + 0.5O_2 = H_2O$$
$$CO + 0.5O_2 = CO_2$$
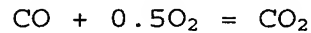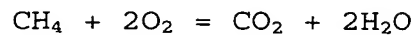
The side reactions are undesirable and reduce the product H_2:CO ratio from a stoichiometric ratio of 2 to a ratio ranging from about 1.7 to about 1.8. The initial reaction is exothermic and produces heat and consequential temperature increases to above about 1300°C. The high temperatures allow the following reforming reactions to occur at the main part of the reactor:

$$CH_4 + H_2O = CO + 3H_2$$
$$CH_4 + CO_2 = 2CO + 2H_2$$
$$CO_2 + H_2 = CO + H_2O$$
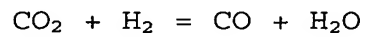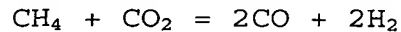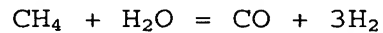
The crude synthesis gas is treated in a separation system to recover a hydrogen or carbon monoxide product. Common separation systems that are employed for such purpose include: membrane separation units; MEA adsorption units, PSA, and cryogenic separation units.

[0004] In steam methane reforming, the hydrocarbon containing stream, steam and, optionally, a recycle stream, primarily containing carbon dioxide, is fed into a reactor. Commonly the reactor is formed by a bundle of tubes containing a catalyst. The tube bundle is located in a furnace and natural gas is also used as a fuel to the furnace. The hydrocarbon containing stream to be reacted is pretreated to remove sulfur which is a poison with respect to the

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reforming catalyst. Typically, the sulfur level in
the natural gas is reduced to a part per million level
before the natural gas is fed into the reactor. The
following reactions take place inside the catalyst
packed tubes:

$$CH_4 + H_2O = CO + 3H_2$$
$$CH_4 + CO_2 = 2CO + 2H_2$$
$$CO_2 + H_2 = CO + H_2O$$
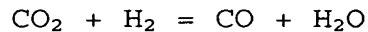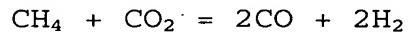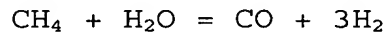
The crude synthesis gas product from the reactor,
which contains hydrogen, carbon monoxide, and water,
is cooled down to avoid the re-reforming of methane
from the carbon monoxide and the hydrogen. The crude
synthesis gas may be treated in a variety of
separation units to remove impurities or to recover a
desired product such as hydrogen or carbon monoxide in
a manner that is similar to that provided for in a
partial oxidation reactor.

[0005]   In autothermal reforming, in a first
reaction zone formed by a burner, natural gas, oxygen
and, optionally, steam and a recycle stream containing
CO_2 are reacted. The reactions in this first reaction
zone are as follows:

$$CH_4 + 2O_2 = CO_2 + 2 H_2O \quad H_2$$

[0006]   The resultant intermediate product from the
first reaction zone containing methane, water, and
carbon dioxide, is fed to a catalyst bed below the
burner where the final equilibration takes place in
the following reactions:

$$CH_4 + H_2O = CO + 3H_2$$
$$CO_2 + H_2 = CO + H_2O$$
$$CH_4 + CO_2 = CO + H_2$$
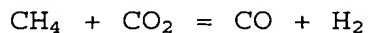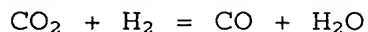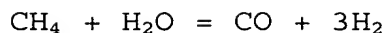
The catalyst bed may be a vessel filled with catalyst as disclosed in U.S. Patent No. 5,554,351 or a fluid bed catalyst system such as disclosed in U.S. Patent No. 4,888,131. In the fluid bed system disclosed in the aforesaid patent, methane and steam are fed to the bottom of the fluid bed and oxygen is fed close to the bottom but inside the fluid bed. The crude synthesis gas can be treated in separation systems such as have been discussed above with respect to partial oxidation units.

[0007] The prior art reactors, such as those discussed above, are designed for large volume production of synthesis gases. They are not amenable to be modified for production on a lower scale in that they require furnaces, fluidized beds, burner, complex controls and etc. U.S. Patent No. 6,471,937 discloses a reactor that by its very nature is capable of being utilized in lower volume applications. In this patent, two reactants are mixed by expanding one of the reactants into a mixing chamber through an orifice and entraining the other reactant to form the mixture. The mixture is formed in such a sufficiently short time that no reaction takes place between the two reactants. The reactants, once mixed, are then reacted with one another in a reaction zone. The problem with this type of reactor is that although it is desirable to use a high surface area high activity

catalyst in reality if the reaction is highly
exothermic the lifetime of such catalyst will be
severely limited.

[0008]   As will be discussed, the present invention
provides a reactor and method that employs an
autothermal reactor in which reactants are mixed
without reaction, in a manner that can take the form
outlined in U.S. Patent No. 6,471,937, and that is
designed to produce a sufficient amount of synthesis
gas product to allow such reactor and method to be
practically utilized for small, on-site production of
synthesis gases.

Summary of the Invention

[0009]   The present invention provides an
autothermal reactor for producing synthesis gas. A
mixing chamber is provided that has an orifice to
expand a heated oxygen containing stream into the
mixing chamber. An inlet to the mixing chamber is
located adjacent to the orifice and oriented to
introduce a hydrocarbon containing stream into the
mixing chamber tangentially to the heated oxygen
containing stream. As a result, the hydrocarbon
containing stream is entrained in the heated oxygen
containing stream to mix oxygen in the heated oxygen
containing stream with hydrocarbons contained in the
hydrocarbon containing stream at a sufficiently rapid
rate so as not to react the oxygen and the
hydrocarbons. This produces a reactant stream that is
made up of an unreacted mixture of the heated oxygen
containing stream and the hydrocarbon containing
stream.

[0010]   An initial partial oxidation reaction zone
having a supported partial oxidation catalyst is in
communication with the mixing chamber. The initial
partial oxidation reaction zone is followed by at
least two endothermic reforming reaction zones heated
by an exothermic reaction of the partial oxidation
reaction zone to react oxygen and hydrocarbons of the
reactant stream and thereby to form the synthesis gas.
The at least two endothermic reforming reaction zones
contain a precious metal catalyst supported on
supports formed of materials that provide a greater
surface area for a successive of the at least two
endothermic reforming reaction zones than an initial
of the at least two endothermic reforming reaction
zones that directly follows the partial oxidation
reaction zone. The initial and the successive of the
at least two endothermic reforming reaction zones are
configured to operate at ever decreasing operational
temperatures such that a material making up a support
of the successive of the at least two endothermic
reforming reaction zones remains stable.

[0011]   The use of multiple reforming zones having
an increased surface area for the supported catalyst
allow for faster reaction rate to take place. This
foregoing feature of the invention coupled with the
rapid formation of the reactant stream allows the
reactor to be compact yet have a production rate of
synthesis gases that is sufficient for small on-site
production.

[0012]   As may be appreciated, given the above
discussion, it would be preferable if all of the
endothermic reforming reaction zones had the increased

surface area. The problem with this is that materials used in providing such increased surface area are not stable at the temperature generated by the partial oxidization reaction, for instance, titania or gamma alumina. The term "stable" when used in connection with such materials means that at high temperatures, the materials undergo a phase transition and lose their high surface area attributes. For instance, in case of gamma alumina, the material will revert to the lower surface area alpha alumina. By having low surface area initial reforming reaction zones followed by the high surface area reforming zone, the high temperatures produced at the partial oxidation zone of the system are reduced sufficiently by the time the reactant mixture reaches the high surface area reforming zone so that the life of the high surface area reforming zone is increased.

[0013] In case of a high surface area gamma alumina support, a phase transition takes place converting the same to low surface area alpha alumina above about 700° C. when un-promoted and above about 900° C. to 1000° C. when promoted. The low surface area alpha-alumina support providing a lower surface area results in lower activity. The mixing chamber can be defined by an inner surface outwardly diverging from the orifice to form a frustum of a cone. The surface outwardly diverges from the orifice at an angle calculated to inhibit re-circulation within the mixing chamber.

[0014] In any embodiment of the present invention, the partial oxidation zone can be formed by a monolithic support and the endothermic reforming zones

can be formed by beds of pellets. Preferably, there
are two endothermic reforming zones. The monolith can
be of honeycomb configuration and the pellets of the
initial of the at least two endothermic reforming
reaction zones can be formed by alpha-alumina and the
successive of the at least two endothermic reforming
reaction zones can be formed by gamma-alumina.
Alternatively the endothermic reforming zones can be
formed by a ceramic or metallic monolith that is
coated with the materials supporting the catalysts,
for instance an alpha or a gamma-alumina layer. A
ceramic heat shield of honeycomb configuration can be
located between the partial oxidation reaction zone
and the mixing chamber to inhibit heat transfer from
the partial oxidation reaction zone to the mixing
chamber.

[0015]   The mixing chamber can be a primary mixing
chamber. In such embodiment, a secondary mixing
chamber can be situated between the partial oxidation
reaction zone and the endothermic reforming zones.
The secondary mixing chamber is provided with a
secondary inlet to receive a recycle stream containing
synthesis gas components obtained by separation of
hydrogen and carbon monoxide from the synthesis gas.
Preferably, the mixing chamber, the partial oxidation
reaction zone and the endothermic reforming zones are
in an inline relationship.

[0016]   The initial of the at least two endothermic
reforming reaction zones can have a surface area from
between about 0.1 and about 10 m^2/gm. The successive
of the at least two endothermic reforming zones can
have a surface area from between about 5 and about 300

m^2/gm. The precious metal catalyst used in the endothermic reforming zones can be Pt, Rh, Ru, Pd, or Ni. The monolith for the partial oxidation reaction zone can be from a ceramic doped with a partial oxidation catalyst, for instance, rhodium, platinum, ruthenium, or palladium.

[0017]   In another aspect, the present invention provides a method of making a synthesis gas. In accordance with such method, a heated oxygen containing stream and a hydrocarbon containing stream are mixed to form a reactant stream. The heated oxygen containing stream and hydrocarbon containing stream are mixed at a sufficiently rapid rate such that oxygen and a hydrocarbon containing content of the hydrocarbon containing stream remain unreacted in the reactant stream. The oxygen and said hydrocarbon content are autothermally reacted within the reactant stream in an initial partial oxidation reaction followed by at least two subsequent endothermic reforming reactions to form the synthesis gas. The at least two endothermic reforming reactions are sustained with heat generated from said partial oxidation reaction and by supported catalyst supported on supports. The supports are formed of materials that provide a greater surface area for a successive of the supports supporting the catalyst involved in a successive of the at least two endothermic reforming reactions than an initial of the supports supporting the catalyst involved in an initial of the at least two endothermic reforming reactions that directly follows the partial oxidation reaction. The initial and the successive of the at least two endothermic

reforming reactions are operated at ever decreasing operational temperatures such that a material making up the successive of the supports remains stable.

[0018]   The heated oxygen containing stream and the hydrocarbon containing stream can be mixed in a mixing chamber by expanding the heated oxygen containing stream into the mixing chamber through an orifice and tangentially introducing the hydrocarbon containing stream into the mixing chamber such that the hydrocarbon containing stream is entrained in the oxygen containing stream. The oxygen containing stream after expansion can have a supersonic velocity and the hydrocarbon containing stream can have a subsonic velocity.

[0019]   The partial oxidation reaction can occur in a temperature from between about 800° C. and about 1400° C. and the initial of said at least two endothermic reforming reactions occurs in a temperature range from between about 1000° C. and about 1200° C. and the subsequent of the at least two endothermic reforming reactions occurs in a subsequent temperature range of between about 700° C. and about 1000° C.

[0020]   A recycle stream containing synthesis gas components obtained by separation of hydrogen and carbon monoxide from the synthesis gas can be introduced into the endothermic reforming reaction zones.

Brief Description of the Drawing

[0021]   While the specification concludes with claims distinctly pointing out the subject matter that

Applicants regard as their invention, it is believed
that the invention will be better understood when
taken in connection with the accompanying drawing in
which the sole figure is a schematic, sectional view
of a reactor for carrying out a method in accordance
with the present invention.

Detailed Description

[0022]   With reference to the Figure, a reactor 1 is
illustrated that is designed to produce a crude
synthesis gas stream 2.

[0023]   Reactor 1 is provided with a fuel injector
tube 10 and a coaxial, outer oxygen passage 12 which
are in communication with a thermal mixing chamber 14
in which the fuel is ignited and burns in the presence
of the oxygen. Ignition is initiated by a spark plug
16. Combustion takes place under fuel lean conditions
such that a resultant heated oxygen mixture is
produced that by in large contains oxygen and also
combustion products produced by combustion of the
fuel.

[0024]   It is to be noted that it is important for
there to be complete combustion of the fuel being used
to heat the oxygen in the oxygen containing stream so
that a flame is not present in the heated oxygen
containing stream upon introduction into a mixing
chamber 20 (to be discussed). The presence of a flame
within mixing chamber 20, indicating incomplete
combustion of the fuel, will promote pre-ignition and
stabilize combustion in the mixing chamber 20. This
is counter productive and undesirable for partial
oxidation. The prevention of flame formation can be

accomplished by moving fuel injector tube 10 within outer oxygen passage 12 such that it is recessed within outer oxygen passage 12 a sufficient distance from orifice 18 to ensure complete combustion of the fuel within thermal mixing chamber 14. The required degree of recess can be rapidly determined by simply moving fuel injector tube 10 within outer oxygen passage 12 until complete combustion is assured.

[0025]   It is understood that other means of preheating the oxygen can be employed. For example, the oxygen can be preheated by heat exchange with crude synthesis gas stream 2 or in a separate furnace in which heat is generated either electrically or by utilizing heat from a combustion process, or waste heat from another process stream.

[0026]   A heated oxygen containing stream composed of the heated oxygen mixture is introduced into mixing chamber 20. Mixing chamber 20 is operable to mix hot oxygen in the heated oxygen containing stream and the hydrocarbons in a hydrocarbon containing stream to form a high temperature reactant mixture comprising the heated oxygen and hydrocarbons. As will be discussed, the method of forming the reactant mixture involving the rapidly mixing of the oxygen and the hydrocarbons and the design of the mixing chamber 20 itself acts to prevent reaction of the oxygen and hydrocarbons within the reactant mixture while in mixing chamber 20.

[0027]   The rapid mixing in mixing chamber 20 is accomplished by expelling the heated oxygen containing stream from thermal mixing chamber 14 through an orifice 18 that acts to expand the heated oxygen

containing stream. The heated oxygen containing stream entrains the hydrocarbons contained within the hydrocarbon containing stream. The hydrocarbon containing stream is introduced into mixing chamber 20 through a tangential inlet 22 that is located adjacent the orifice 18. Although only one tangential inlet 22 is illustrated, there are multiple inlets such as tangential inlet 22, preferably eight radial inlets that are equally spaced at 45^0 from one another. Preferably, the heated oxygen containing stream enters mixing chamber 20 with an oxygen purity of about 87% by volume, a temperature in a range of between about 1300°F and about 3200°F., and a velocity in a range of between about mach 1.05 and about mach 2. Subsonic velocities could be used but would produce less rapid mixing.

[0028]   Orifice 18 is preferably fabricated from 316L stainless steel, with a thickness of about 0.5 inches, a rocket style rounded entrance, a straight throat and a diverging angle to the nozzle exit designed to produce supersonic velocities. The computation of the appropriate diverging angle is well known to those skilled in the art and depends on the pressure differential across the orifice and desired velocity and is typically less than about 3 degrees.

[0029]   The pressure in the thermal chamber 14 is at least 1.2 times, preferably at least 1.5 times and more preferably at least 2 times the pressure in the mixing chamber 20.

[0030]   As mentioned above mixing chamber is preferably designed to inhibit reaction of the oxygen and the hydrocarbons. Such design includes forming

mixing chamber 20 in the shape of a frustum of a cone
with sides that outwardly diverge from an apex at
which the hydrocarbon containing stream is
tangentially introduced through tangential inlets 22.
Preferably, the sides of mixing chamber 20 diverge at
an angle of about 10 to 20 degrees with the apex of
the cone which is closest to the thermal nozzle sized
at 1.5 times the largest thermal nozzle diameter to be
used. This is to minimize the recirculation of hot
gases and thereby help prevent the unwanted reaction
within mixing chamber 20. Water cooling is also
provided to draw off heat from the surface to avoid
overheating of the surface of mixing chamber 20.
Water is circulated through reactor 1 to draw off heat
from mixing chamber 20 through a surrounding water
passage having a water inlet 24 and outlet 26.
Reaction is also avoided in mixing chamber 20 due to
its short length which acts to reduce the residence
time of the reactant flowing within mixing chamber 20.
Preferably, the length of mixing chamber 20 is sized
such that the reactant containing gas mixture will
move through it is less than 3 milliseconds.

[0031]   Preferably, the resultant reactant stream
flows from mixing chamber 20 into a honeycomb monolith
28 formed of a ceramic, preferably Alumina. Honeycomb
monolith 28 acts as a heat shield to minimize radiant
heat loss from subsequent catalytic reaction zones to
be discussed hereinafter back to the mixing chamber
20. The reactant stream from mixing chamber 20
expands to the diameter of the honeycomb monolith 28
and flows straight through it for another millisecond.

[0032]   The reactant stream then enters a partial oxidation zone 34 which can be from a ceramic doped with a partial oxidation catalyst. The catalytic doped ceramic monolith can be made of a foam or have straight channels in a honeycomb arrangement. In case of foam, the pore size is preferably between about 1 and about 4 millimeters in diameter. Rhodium, platinum, ruthenium or palladium are preferred catalysts for synthesis gas production. Rhodium is the most preferred and is preferably present within the monolith in an amount of between about .5 percent and about 5. percent by weight. If a foam is used, the foam can be either a yttria stabilized zirconia and alumina (YZA) or about 99% alumina.

[0033]   Partial oxidation zone 34 is the highest temperature zone in the reactor. Most of the oxygen will be reacted in this zone. Residual oxygen will be less than about 10% by dry volumetric gas analysis. The reaction of the oxygen and hydrocarbon gases is exothermic initially and forms some complete products of combustion such as carbon dioxide and water and also some amount of carbon monoxide and hydrogen. The heat generated by the oxidation reactions in partial oxidation zone 34 is then available to drive endothermic reforming reaction of the fully oxidized species and methane to carbon monoxide and hydrogen. The reforming reaction takes place in sequential, second and third endothermic reforming reaction zones 36 and 38.

[0034]   The residence time of the reactants within partial oxidation zone 34 is preferably from between about 0.1 and about 2 milliseconds, the temperature is

between about 800° C. and about 1400° C., more preferably between about 1000° C. and about 1370° C., and the pressure is preferably about 1.5 to about 30 atm absolute.

[0035]   Endothermic reforming zone 36 can be formed by alpha alumina pellets doped with platinum. The alpha alumina pellets may be spherical or cylindrical and have an effective diameter of between about 3 mm and about 100 mm. Preferably endothermic reforming reaction zone 36 has a diameter to length ratio of between about 5 and about 2 and the residence time in this stage is preferably between about 0.5 and about 2 milliseconds. Alpha alumina is not temperature sensitive and therefore, can operate at high temperatures.

[0036]   The next sequential endothermic reforming reaction zone 38 operates at a lower temperature than endothermic reforming reaction zone 36 due to the fact that some heat generated in partial oxidation reaction zone 34 has been consumed in endothermic reforming reaction zone 36. In this regard, the operating temperature and pressure of endothermic reforming reaction zone 38 is preferably between about 700° C. and about 1000° C. and about 1.5 to 30 atm, respectively. The operating temperature of endothermic reforming reaction zone 36 is preferably between about 1000° C. and about 1200° C.

[0037]   Endothermic reforming reaction zone 38 takes advantage of the heat consumption of endothermic reforming reaction zone 36 by utilizing a material for the support that is designed to provide a greater surface area for reaction than endothermic reforming

reaction zone 36. Endothermic reforming reaction zone
38 preferably consists of a platinum catalyst, between
about 0.5% and about 5% by weight, on a gamma alumina
support preferably in the form of 3 to 100 mm diameter
spherical pellets. The support provides a surface
area from between about 5 and about 300 m^2/gm. This is
to be compared with the surface area provided by the
support of endothermic reforming reaction zone 36
which is preferably between about 0.1 and about 10
m^2/gm. In addition, endothermic reforming reaction
zone 38 is also sized to produce a longer residence
time for the reactants than endothermic reforming
reaction zone 36, namely, between about 5 and about 20
milliseconds.

[0038]   Reactor 1 is an autothermal reactor since
heat generated by the partial oxidation reaction
drives the endothermic reforming reactions. The
inline relationship of the aforesaid reaction zones
helps to maximize heat utilization. Available heat
utilization is also increased due to the use of
ceramic insulation 40 which is provided radially
outward from honeycomb monolith 28, partial oxidation
zone 34 and endothermic reforming reaction zones 36
and 38. In this regard insulation 40 preferably has a
thickness from between about 6 and about 12 inches and
is advantageously a bubble form of tabular alumina
castable refractory.

[0039]   Reactor 1 utilizes steel construction
outside of the insulation 40 to form a pressure vessel
strong enough to contain the operating pressure plus a
safety margin typically three to five times the
operating pressure.

[0040]   The reactant stream, prior to entering
endothermic reforming reaction zone 36 can be
bolstered with a recycle stream introduced into
secondary mixing chamber 41 through an inlet 42. The
recycle stream is a by-product of downstream
purification units used in the manufacture of a
synthesis gas, hydrogen or carbon monoxide products.
If the recycle stream is free of hydrogen it may be
added to the mixing chamber 20. However if the
recycle stream contains hydrogen it is not desirable
to add it to mixing chamber 20 due to possibility of
homogeneous ignition of the hydrogen with the hot
oxygen. The recycle stream besides recovering
unreacted hydrocarbons such as methane, cools the
reactant stream from partial oxidation zone 34. The
recycle stream, however, may be heated to reduce the
cooling effect; provided, however, the temperatures
and residence times are controlled and certain
materials for reactor 1 (e.g. high nickel containing
alloys) are avoided that will favor the re-reforming
of carbon monoxide and hydrogen if present in the
recycle stream.

[0041]   The ratio of the recycle to the hydrocarbon
that is fed to the mixing chamber is preferably no
greater than about 3. The recycle stream may contain
hydrogen, carbon monoxide, carbon dioxide, and
methane. None of the foregoing constituents within
the reactant stream is present in an amount that is
more than 50% by volume. The hydrogen content is
preferably between about 5% and about 50% by volume.
The carbon monoxide content is preferably between
about 10% and about 30% by volume. The carbon dioxide

content is preferably between about 1% and about 20% by volume and the methane content is preferably between about 1% and about 10% by volume.

[0042]   The resultant crude synthesis gas stream 2 should be quenched quickly after exiting endothermic reforming reaction zone 38 so that the temperature is less than about 800°F and preferably less than about 500°F. Such quenching can be accomplished by expanding the crude synthesis gas stream 2 through an expansion nozzle 43 in communication with a water cooled chamber 44 surrounded by a water passage having a water inlet 46 and a water outlet 48. Although not illustrated, the pellets making up endothermic reforming reaction zone 38 can be held in place relative to water cooled chamber 44 by a wire mesh, ceramic honeycomb structure or the like. It is to be noted that such cooling could be effected more slowly by heat exchange to one of the incoming process gas streams to preheat it or by heat exchange with water to generate steam.

[0043]   Crude synthesis gas stream 2 may then be introduced into a separation system to produce hydrogen and carbon monoxide products or a synthesis gas product containing hydrogen and carbon monoxide. The separation system maybe a membrane, a cold box, a pressure swing adsorption unit, an amine CO_2 separation unit or a combination of the four. As may be appreciated, in any such separation systems, carbon dioxide and methane or other hydrocarbon content that is left unreacted will be separated. This separated content is preferably recycled.

[0044]   The following examples are set forth for purposes of illustrating operation of reactor 1 and not for any purposes of limitation. These examples illustrate the operation of Reactor 1 with propane, propane and recycle, natural gas, and natural gas with recycle.

Example 1

[0045]   Reactor 1 was constructed with a partial oxidation zone 34 formed of a catalytic monolith as described above, an endothermic reforming reaction zone 36 of approximately 30 cm^3 in volume and having a 1% by weight rhodium on alpha alumina cylindrical pellets and a subsequent endothermic reforming reaction zone 38 containing approximately 270 cm^3 of platinum, between about 0.5% and about 1% by weight on gamma alumina spherical pellets of about 3 mm. diameter. A nozzle diameter of 16 mm was used for orifice 18. The orifice 18 was fed with about 101 scfh oxygen and about 3 scfh of propane. An additional amount of about 65 scfh of propane was added to the mixing chamber 20. The mixture was reacted over the monolith forming partial oxidation zone 34 without passage to a subsequent endothermic reforming reaction zone. The reactor effluent was cooled to condense water and then analyzed. The composition of the dry product gas was as follows:

gas	CO_2	C_3H_6	C_3H_8	C_2H_2	C_2H_4	C_2H_6	CH_4	CO	H_2	O_2	N_2
mole fraction	0.826	0.0288	0.1412	ND	0.4527	0.035	4.2107	39.425	53.393	0.482	0.558

Example 2

[0046]   Reactor 1 was constructed in the manner outlined above with respect to Example 1. The orifice 18 was fed with about 122 scfh oxygen and about 3 scfh propane. An additional amount of about 64 scfh of propane was added to the mixing chamber 20. About 151 scfh of a recycle gas stream containing on a per volume basis: about 1.15% carbon dioxide, about 41.49% hydrogen, about 5.21% methane and the balance carbon monoxide was introduced to the secondary mixing chamber 30. The reactor effluent was cooled to condense water and then analyzed. The resultant composition of the product gas was as follows.

gas	CO_2	C_3H_6	C_3H_8	C_2H_2,C_2H_4,C_2H_6	CH_4	CO	H_2	O_2
mole fraction %	1.00	0.02	0.04	Not Detectable	0.33	42.6	54.8	0.42

Example 3

[0047]   Reactor 1 was constructed in the manner outlined above with respect to Example 1 except that orifice 18 had a diameter of about 22 mm. The following table summarizes the experimental feed conditions.

O_2 to orifice 18 (scfh)	Natural Gas to orifice 18 (scfh)	Natural Gas to mixing chamber 20 (scfh)
100.0	10.0	198

The resultant crude synthesis gas stream 2 was cooled to condense water and then analyzed. The composition of the product gas was as follows.

gas	H_2	CO_2	C_2H_4	C_2H_6	C_2H_2	O_2	N_2	CH_4	CO
mole fraction %	58.37	4.97	ND	0.05	ND	ND	0.99	9.34	26.15

Example 4

[0048]   A reactor 1 was constructed in the manner of example 1 with an orifice 18 of about 16 mm. Orifice 18 was fed with oxygen and natural gas. In addition natural gas was added to the mixing chamber 20. A recycle gas stream containing on a volume basis: about 1.15% carbon dioxide, about 41.49% hydrogen, about 5.21% methane and the balance carbon monoxide was added between the partial oxidation zone 34 and the endothermic reforming zone 36. The following table summarizes the experimental feed conditions.

Oxygen to orifice 18 (scfh)	Natural Gas to orifice 18 (scfh)	Natural Gas to mixing chamber 20 (scfh)	Recycle stream (cfh)
100	2.8	195	201

The crude synthesis gas stream 2 was cooled to condense water and then analyzed. The composition of the crude synthesis gas stream 2 was as follows:

gas	H_2	CO_2	C_2H_4	C_2H_6	O_2	N_2	CH_4	CO
mole fraction %	51.50	4.02	0.0346	0.0523	0.	0.8531	9.9125	32.74

[0049]   As may be appreciated by those skilled in the art, while the present invention has been discussed relative to a preferred embodiment, numerous, changes, additions, and omissions can be made without departing from the sprit and scope of the

present invention as set forth in the following
appended claims.